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# Uses for Marine Mattresses in Coastal Engineering

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**PURPOSE:** The Coastal and Hydraulics Engineering Technical Note (CHETN) described herein provides basic information on the Triton Marine Mattress System,[1] describes potential applications for marine mattresses in coastal engineering and summarizes previous successful deployments of marine mattresses in projects by the U.S. Army Corps of Engineers and others.

**DESCRIPTION OF MARINE MATTRESSES:** Marine mattresses are rock-filled containers constructed of high-strength geogrid as shown in Figure 1. Geogrid panels are laced together to form mattress-shaped baskets that are filled with small stones similar to construction of gabions. The Triton Marine Mattress System was developed by the Tensar Corporation, manufacturer of the geogrid panels used to form the mattress. The system is not patented, and the mattresses could be constructed using similar geogrid products from another manufacturer. However, as of the date of this CHETN, all mattress applications in the United States have been made using Tensar geogrid.

Figure 1. Portion of marine mattress showing geogrid container (photograph by Kevin Knuuti, Coastal and Hydraulics Laboratory (CHL))

[1] This CHETN attempts to provide a balanced description of the Triton Marine Mattress System and how the product can be used on coastal projects. This technical note should not be considered an official Corps of Engineers endorsement or recommendation of the Triton Marine Mattress System or of the private company Tensar Earth Technologies, Inc., that manufactures the geogrid panels.

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Typical width for a single marine mattress is about 5 ft, but this can vary according to placement plan and contractor capability. Mattress lengths vary up to a recommended maximum of 35 ft. Mattress thickness is usually between 8 and 12 in. for revetment applications, but thicknesses can vary between 4 in. for bedding layers up to 24 in. for heavy-duty applications exposed to waves and currents. Assuming the stone fill has a volumetric weight of about 110 lb/cu ft, a 35-ft-long, 5-ft-wide, 1-ft-thick mattress weighs approximately 9.6 tons. The high-strength geogrid has sufficient strength to permit rock-filled mattresses up to 35 ft in length to be hoisted from one end for placement at the project site. However, keep in mind this guidance is for mattresses 12 in. thick or less. Check with the geogrid manufacturer for maximum mattress lengths associated with mattresses thicker than 12 in. and widths of about 5 ft. Figure 2 shows a stack of marine mattresses prior to placement. Figure 3 shows lifting of a mattress from both ends. The cellular construction of the mattress using internal diaphragms maintains the uniform thickness of the stone fill material during the lifting and placement operations.

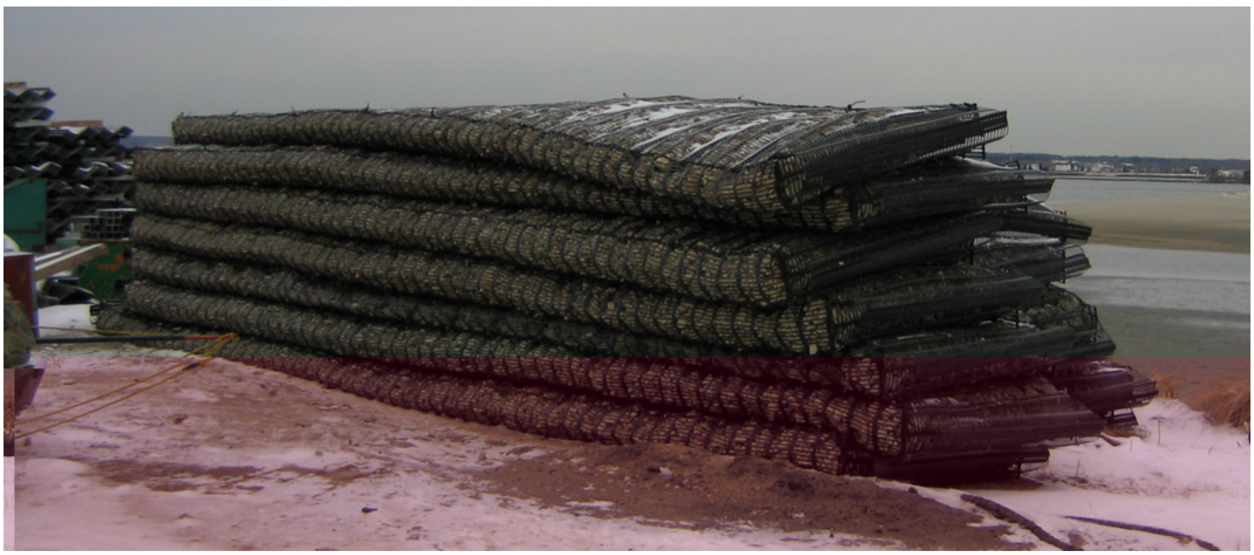

Figure 2. Stack of filled marine mattresses staged for placement on National Shoreline Erosion Control Development and Demonstration Program (Section 227) project in Seabrook, NH (photograph by Kevin Knuuti, CHL)

**USES OF MARINE MATTRESSES IN COASTAL ENGINEERING:** A marine mattress is a large, monolithic unit with porosity similar to placed riprap or some bedding layers. Several applications of marine mattresses in coastal projects (Olsen 2001) are described in the following sections.

**Revetment Units for Low to Moderate Wave Exposure.** A common application for marine mattresses is bank protection for rivers and shorelines of protected bays and lakes. Because of the geogrid container, the mattresses will tolerate more wave action than comparable revetments made of significantly larger loose stone. When protecting sand or soil, appropriate filter layers of gravel or geotextile filter cloth must be included in the cross-section design. A primary mattress failure mode under wave action is failure of the geogrid or the lacing that holds the panels together. If this occurs, the stones will no longer be confined, and the mattress could

Figure 3. Installation of mattress at Barnegat Inlet, NJ (photograph courtesy of Tensar Earth Technologies)

start to unravel. For wave protection applications, stone movement within the mattress must be minimized to preclude interior wear of the mattress containment geogrid superstructure. Movement of an entire mattress unit by wave action is also a potential failure mode under severe wave condition. Mattresses placed on steep slopes without adequate toe buttressing or tieback anchors at the top could slide downslope as a unit, or the mattresses could fail by buckling if waves are powerful enough to lift portions of the mattress and the mattress is not properly compartmentalized.

Limited data exist on marine mattress maximum tolerable wave height without damage. Brown (1979) developed minimum thickness guidelines for stable gabion revetment applications exposed to waves. Formulas were given for both downslope stability and for uplift stability, i.e.,

$$, \geq \frac{}{2.8 \cot \theta ( \quad -1) (1- \quad )} \qquad \text{for downslope stability} \qquad (1)$$

$$, \geq \frac{}{7.0 (\cot \theta)^{1/3} ( \quad -1) (1- \quad )} \qquad \text{for uplift stability} \qquad (2)$$

where and are minimum mattress thicknesses, is the design wave height (assume breaking wave height for depth-limited conditions or for nonbreaking waves), cot θ is the inverse of the revetment slope, is the stone fill specific gravity (2.65 for granite-like rock), and is the voids allowance of the stone fill (typically about 0.35). Equations 1 and 2 were developed for gabions, so applying this guidance to marine mattresses is tentative until such time new tests specific to mattresses are conducted. A safety factor should be considered for critical applications.

Equations 1 and 2 are shown graphically on Figure 4 using typical values of = 2.65 and = 0.35. Cotangent of revetment slope is plotted on the abscissa, and wave height divided by mattress thickness is plotted on the ordinate. On slopes steeper than about 1-on-4 ( θ = 4) the down-slope stability criterion (black line) governs. On milder slopes, the uplift stability criterion should be applied. For example, a revetment with a slope of 1-on-2 should be able to resist wave heights up to about = 6 ft for a 12-in.-thick mattress or = 4 ft for an 8-in.-thick mattress. Securing the top of the mattress using anchors that extend landward beyond the soil failure zone will provide additional protection against downslope failure. Once again, this stability guidance is tentative, and caution must be exercised until additional tests become available.

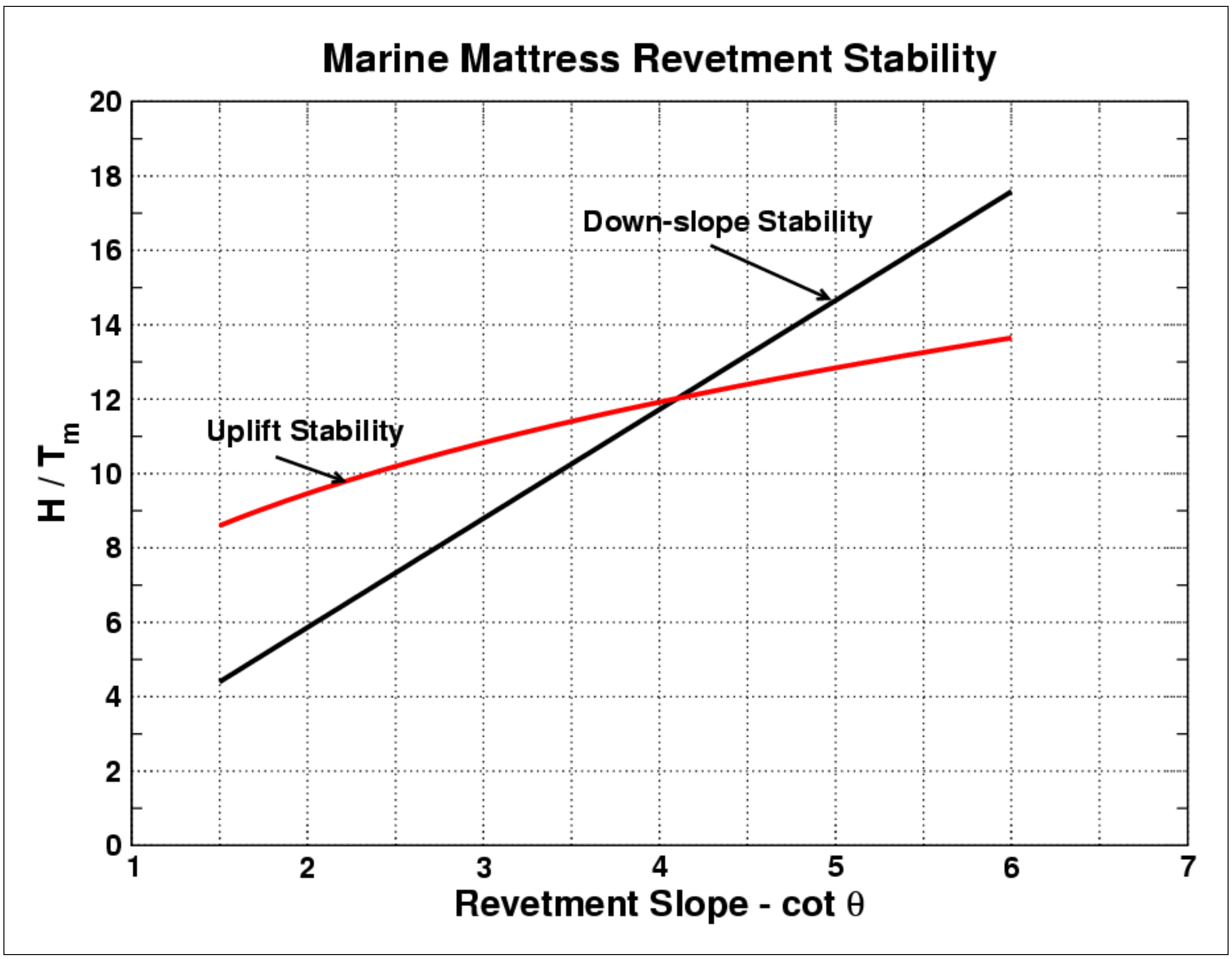


Figure 4. Marine mattress wave stability for revetment applications

**Underlayer for Rubble-Mound Structures.** Larger coastal structures exposed to bigger waves consist of a core covered by one or more underlayers of progressively larger stone, and an armor layer of large stones or concrete armor units. Mattresses could be deployed as an underlayer for some rubble-mound structures. If placed as the layer directly beneath the primary armor, the mattress container will help retain underlayer material if the overlying armor is displaced, thus preserving structure integrity until repairs can be made. In addition, the mattress containment allows use of smaller stones than would normally be needed to meet filter requirements for unconfined underlayers. However, mattresses will be less permeable as a first underlayer than conventional stone underlayers resulting in more wave runup/overtopping. This could allow greater hydrostatic head differential within the rubble-mound structure. Underlayer mattress thickness should be about 6 in. minimum. This thickness provides good weight and rigidity for underwater placement, and mattresses can be filled while laying horizontal.

Because of the geogrid smoothness and the uniformity of the mattress surface, the interface between the mattress and the overlying layer has less shear resistance than a comparable unconfined underlayer. Thus, there could be a greater risk of armor layer slumping on steep slopes with a marine mattress underlayer unless a reliable toe is placed. In more energetic wave climates requiring larger armor stones, mattresses will not be appropriate as the first underlayer, but they might be suitable as the first sublayer over the structure core. For applications where primary armor is placed directly on top of marine mattresses, great care must be taken not to damage the geogrid containers. Whereas the geogrid is tough and can withstand impacts from dropped armor stones, the geogrid can be torn if armor stones are pushed into place using an excavator. Once torn, mattress performance is impaired, and progressive damage is possible.

**Toe Protection.** Marine mattresses can be used for structure toe protection at locations where the toe is not exposed to direct breaking wave heights greater than about 5 ft. This wave height is near the lower end of revetment stability guidance for 12-in.-thick mattresses shown in Figure 4. For breaking wave heights greater than 5 ft, toe protection should be designed using larger stone according to guidance given in the (Burcharth and Hughes 2002). Whereas it is best to have the toe protection mattress tied into the structure, mattresses can be placed at the toe of existing or recently completed structures in the same way scour aprons are placed. Guidance is given in the for widths of scour aprons for vertical wall structures based on geotechnical and hydraulic criteria. If mattresses are placed as the structure-bedding layer for a rubble-mound structure, they can also serve as toe protection by extending the mattress beyond the structure toe. As scour occurs at the outer edge of the mattress, the outer portion of the mattress becomes buried, thus preventing further scour.

**Scour Mats at Inlets or Other Environments Where Fluid Erosional Forces Are Significant.** Scour blankets constructed of placed stone have long been used to stem scour that occurs at inlet jetties and breakwaters or erosion that occurs in riverine environments. Design guidance for stone blankets specifies a stable stone size and a layer thickness to provide adequate coverage. Achieving adequate layer thickness for subaqueous placement is often difficult, which has resulted in specification of increased layer thickness to compensate for placement irregularities. Using marine mattresses for this application may or may not reduce stone size or material quantities, but the mattresses are easier to place and they assure uniform coverage when

placed underwater. Mattress thickness could be as little as 4 in. if the unit weight per area is determined to be sufficient to prevent movement or uplifting. When placed over erodible material, the outer edges of the mattresses will self-bury to provide protection against additional scour. If the bottom material is hard, the mattresses should be checked for potential uplifting at the edges. Mattresses can also be installed to stabilize bedding stone at existing structures that are experiencing erosion or subsidence in the vicinity of the structure toe.

**Scour Prevention Mats in Advance of Construction of Coastal Structures.** Where currents are strong, significant scour can occur during construction of groins, breakwaters, and jetties. For example, Lillycrop and Hughes (1993) described scour that occurred during construction of the Oregon Inlet, NC, terminal groin. Placing scour protection in advance of construction reduces scour, and correspondingly, reduces the amount of material needed to achieve the structure cross section. Marine mattresses can be placed rapidly with uniform coverage; and because of their size and stability against currents, scour protection could extend much farther in front of construction. Finally, the mattresses could also serve as foundation mats for the overlying structure as it advances into deeper water.

**Structure Foundation Mats and Bedding Layers Where Erosion Is Problematic or Foundation Soil Strength Is Poor.** Coastal structures are typically massive gravity structures that exert significant loads on foundation soils. Constructing structures on poor soils with lower strength has always been challenging. Marine mattresses will help distribute loads over a larger area because the geogrid container reduces differential settlement where soil strength varies. However, mattresses will not eliminate differential settlement, so this must be anticipated in the design. Stones in marine mattresses used solely for foundations and/or bedding layers are less likely to move around, and the mattresses may not require the high degree of compaction and grading of stone fill as is required for mattresses exposed directly to wave impact or tidal current influences. It is important to remember that placement of mattresses as foundation mats does not guarantee a stable structure, and a geotechnical foundation investigation is always needed to determine whether the soil will support the overlying structure. Also, mattresses placed directly over sand or soil will not stop leaching of foundation material exposed to flow. To prevent loss of underlying material, first place either a bedding layer of smaller stones or a geotextile fabric on the soil or sand. To facilitate placement of the geotextile fabric in subaqueous applications where waves or current make placement of geotextile fabric difficult, the fabric can be preattached to the marine mattress with additional steps taken in prefabrication to help assure proper overlap of the fabric as the mattresses are placed. Geogrid can be procured with geotextile fabric already attached.

**Pipeline and Outfall Protection.** Marine mattresses could conceivably be used to protect unburied pipelines exposed to current and wave action. The mattresses can be placed rapidly, and the monolithic weight restricts movement of the pipe. In addition, the porous nature of the mattress dissipates wave energy. No design guidance is available at present to predict mattress stability under given wave action and/or current for this application. Pipelines running through the surf zone should always be buried to a depth beneath the expected profile erosion under worst-case scenario.

Olsen (2001) listed circumstances that might be favorable for application of marine mattresses:

Irregular subgrade surfaces on soft/poor soils.

Steep slopes (above or below water).

Areas prone to breaking wave energy, wave runup, or wave reflection.

Saltwater environments.

Offshore deployment or emergency type repairs.

Locations where wave or flow conditions impact the stability of an existing structure's perimeter or leading edge, e.g., protection against flanking of the structure.

Specific examples of completed successful coastal projects that deployed marine mattresses are presented in a later section of this technical note.

**ADVANTAGES OF MARINE MATTRESSES:** Marine mattresses have several important attributes that make them suited for coastal construction.

**Offsite Construction.** Because marine mattresses can be easily lifted and moved, the units can be constructed away from the project site, transported by truck or barge, and placed accurately using locally available equipment. This is particularly useful at sites with limited space for stockpiling materials.

**Fabrication Quality Control.** The technique of mattress construction, and the ability to view the entire mattress after completed helps assure high quality mattresses before placement at the project site.

**Locally Available Materials.** Because marine mattresses require rock fill of relatively small size, many project sites have a local source of fill material. Thus, material transportation costs may be reduced.

**Rapid Placement.** Being able to place mattresses rapidly has an advantage when working in open coast tidal environments with limited periods of slack water or where the wave climate does not provide lengthy time windows of relatively calm conditions. Rapid placement also reduces the time expensive equipment must be onsite and the need to construct cofferdams to accomplish work in dry conditions.

**Underwater and Deepwater Placement.** Controlled underwater placement of stone blankets and bedding layers constructed of unconfined stone is difficult, particularly in deeper water or in low visibility situations. Achieving correct layer thickness often involves placing more stone than originally planned, and verifying layer thickness is costly and time consuming. Weak spots occur where the stone placement misses small patches or coverage is inadequate, and these may be starting points for progressive damage. Marine mattresses help alleviate

difficulties in underwater placement because they are large units with uniform thickness that can be butted up to one another. However, achieving accurate placement is challenging so it may be necessary at times to cover the gap between adjacent mattresses with overlying mattresses. Also important is including an extra flap of geotextile fabric supported by geogrid on both edges of the mattress to assure coverage of the underlying soil. The U.S. Army Engineer District, Philadelphia, reported that a combination of Global Positioning System (GPS) and multibeam sonar allowed the crane operator at a recent installation to move mattresses in 1-ft increments to achieve coverage in depths up to 50 ft. Edges of mattresses not in contact with neighbors were clearly seen on the imagery. An additional benefit of mattresses placed underwater is that stone is not lost during installation because of the geogrid containment.

**Hydraulic Stability.** The high-strength geogrid container creates large, monolithic units that remain stable under wave and current conditions that would destroy unconfined structures built with substantially larger stones. Increasing stone size within the mattress does not increase the overall mattress stability.

**Mattress Size Uniformity.** Well-constructed marine mattresses have consistent dimensions so they can be placed in patterns without large gaps between mattresses. This assures uniform coverage for applications such as bedding, revetments, or scour blankets. However, it does not guarantee that underlying material will not be lost through gaps between mattresses. Damaged mattresses can be removed, and replacements fabricated to the same dimensions. However, removal of damaged mattresses is often difficult after the lifting bars are removed, so a better option might be in situ repair by stitching on additional geogrid (if accessible), or by simply covering the damaged area with additional mattresses.

**Uniform Mattress Porosity and Energy Dissipation.** Marine mattresses will have uniform porosity and consistent energy dissipation characteristics if they are filled with similar-sized stones and are compacted in a similar fashion to provide the same void ratio. Specific wave energy dissipation data for revetment applications are not available, but expect similar or slightly less dissipation than would be achieved for a revetment constructed of similar-size stones to the same thickness. The mattresses have a rough, permeable surface that will reduce wave runup compared to smooth, impermeable revetments.

**Strength and Flexibility.** The geogrid containment structure is strong, and the completed mattresses are flexible enough that they conform to usual topography and bathymetry changes. For example, mattresses used in dikes or levees can cover the seaward slope, drape over the levee crest, and extend down the backside slope. This stabilizes the structure crest and provides protection to the backside slope against overtopping waves.

**Fill Material Is Confined.** The confining geogrid of marine mattresses prevents the rock fill from being transported away from the application site to adjacent beaches. This confinement not only preserves the integrity of the structure, but it also keeps adjacent areas free of loose stone. Marine mattresses have been in service at several locations for up to 10 years, and this indicates good service life for the confining geogrid. Data are insufficient at this time to specify long-term project life, so designs expected to survive for longer periods should anticipate periodic inspection and maintenance to combat long-term aging effects.

**MATTRESS CONSTRUCTION AND INSTALLATION GUIDELINES:** Tensar Corp. provides a set of recommended specifications for the Triton Marine Mattresses System available at the Web site . The mattress construction and installation guidelines in the following paragraphs are based on the Tensar Corp. specification document.

**Materials.** The materials used in fabricating marine mattresses consist of geogrid, mechanical connectors, braided lacing, and stone fill.

**Structural geogrid.** The geogrid is made of high-density polyethylene (HDPE) and/or polypropylene (PP), and it is manufactured so there is complete continuity of all properties throughout its structure. The geogrid material is stabilized against ultraviolet radiation deterioration. Two types of geogrid are used in construction of a mattress containment structure. The stronger Type 2 uniaxial geogrid has a breaking tensile strength of 6,908 lb/ft, and it is used for all exterior sides of the mattress (top, bottom, and sides) and the lifting loops. Type 1 biaxial geogrid has breaking tensile strength of 3,330 lb/ft, and it is used for interior compartment dividers.

**Mechanical connectors and braided lacing:** Mechanical connectors used in mattress construction should be made of high-density polyethylene. These connectors resemble long rods having nominal diameter of three-eighths in. (Figure 5). Metal connectors should not be used. Braided lacing used for tying and lacing the geogrid panels into a mattress with interior compartments should be fabricated of high-density polyethylene eight-strand braid having a nominal diameter not less than three-sixteenths in. and a breaking strength not less than 400 lb. The braid must be stabilized against ultraviolet deterioration. Braid lacing resembles tow ropes used by water skiers, but with ultraviolet (UV) stabilization (Figure 5).

**Stone fill.** Stones used to fill the mattress compartments must be durable, free of cracks or other defects, and have specific gravity of at least 2.5. The absolute minimum stone size needed for retention within the mattress container is least 1.5 in. over the shortest dimension. The preferred minimum is 2.0 in. Maximum stone diameter should be about 6 in. The recommended average stone diameter for a 12-in.-thick marine mattress should be about 4 in. A narrow distribution in stone size will result in a more porous mattress than a well-compacted wide distribution where smaller stones fill the voids between larger stones.

**Fabrication.** Marine mattress construction consists of fabricating the mattress containment structure, and then filling the containment with stones.

**Connections.** The joints where the ends and baffles of each unit join the top or bottom of the unit should be made with a mechanical connector between geogrid elements as illustrated in Figure 5. Cable ties hold the mechanical connector rods in position prior to placement of the fill material. Mechanical connectors carry the load when the units are lifted, and thus, are important. Stitched seams also carry load because they contain the rock fill.

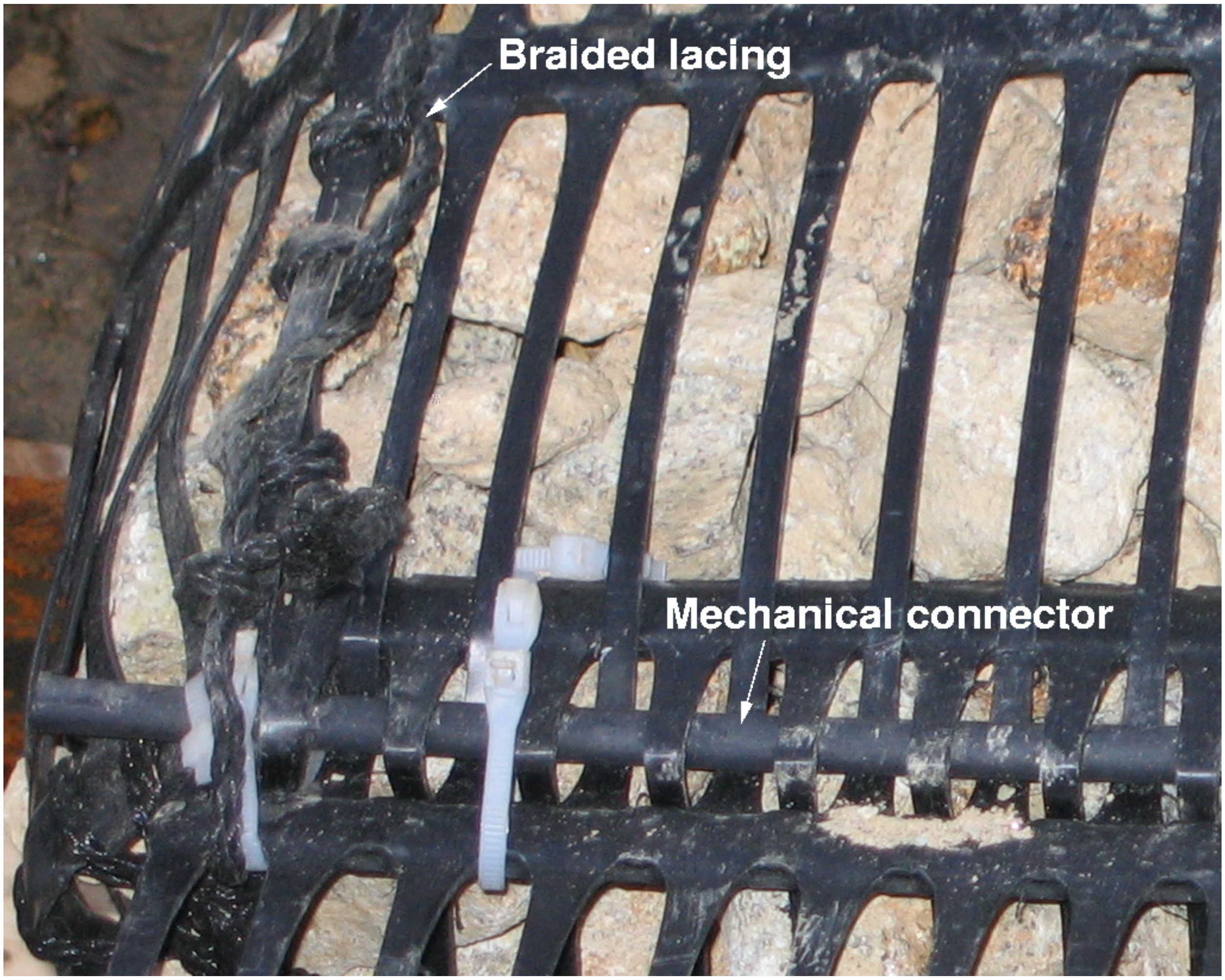


Figure 5. Mattress detail showing mechanical connector and braided lacing (photograph by Kevin Knuuti, CHL)

**Seaming.** Seams are stitched using lengths of braided lacing that have been knotted within 1 or 2 in. of the ends to prevent unraveling. The starting end of the lacing is securely knotted to the geogrid, and the seam joining two adjacent panels is laced with stitches spaced approximately six per foot along the seam. The lacing must be stitched through each pair of apertures along the seam at least once, and the stitches must be sufficiently tight to close the gap between adjacent geogrid panels. Figure 5 illustrates proper lacing of the panels. The braided lacing must be knotted to the geogrid at spacing not to exceed 6 ft along the seam. This technique reduces potential loss of material if the lacing fails. The seam is terminated by securely knotting the lacing to the geogrid. Pieces of braided lacing may be spliced end-to-end by securely knotting.

**Stone fill.** The geogrid mattress containers are most often placed in a construction jig that supports the mattress vertically with the long dimension lying horizontal as shown in Figure 6. Mattress compartments are filled in lifts not to exceed 3 ft for loose material or 2.5 ft for packed stone. The final lift height should be less than 9 in. high, including a 2-in. overfill on the compartment.


Figure 6. Construction jig used to fill marine mattresses at Section 227 project in Seabrook, NH (photograph by Kevin Knuuti, CHL)

Each lift should be tightly packed (except the final lift) by rodding and/or vibration. Compacted stone fill should exhibit the following characteristics: (a) tightly confined stones that will be immobile within the mattress structure, (b) tensioned interior diaphragms, (c) snug mechanical connections and seams, (d) slight bulging of compartments, and (e) no evidence of air space between compartments during lifting. Avoid overpacking of the compartment that causes excessive bulging of the unit or interior diaphragms, and care must be taken that filling and compacting does not cause excessive damage to the geogrid or laced seams. Mattresses intended only for foundation or bedding layers do not need to be as thoroughly compacted. Stitching the top panel into place along the entire length completes the mattress filling operation.

An alternate filling method is to place the mattress horizontal with the sides and diaphragms held in place with removable wooden forms. Mattresses are filled using a front-end loader, fill is compacted, and the top is then stitched onto the mattress. The next mat can be constructed directly on top of the completed mattress, resulting in a stack of mattresses. Horizontal construction is more efficient for thinner mattresses intended for underlayer or scour mat application.

Lifting loops are constructed on both ends of the mattress' long dimension by joining the upper and lower geogrid layers as shown in Figure 1. Mechanical connectors must be used to secure the lifting loops to the mattress. Once completed, the mattress is rotated out of the construction jig to a horizontal position, a lifting pipe and harness is fitted to the lifting loops, and the

completed unit is moved by a crane to a staging area or placed on a flatbed truck for transport to a remote project site. If the mattress is to be placed on top of a geotextile filter cloth, it may be feasible to preattach the filter cloth to the bottom of the mattress with provision for sufficient overlap of geotextile to assure complete coverage at placement.

**Installation:** Marine mattress installation involves site preparation and placement of the units. Mattress anchoring might be specified for mattresses placed on slopes and exposed to waves and/or current.

**Placement.** Prior to mattress installation, the underlying layer (soil, sand, bedding layer, filter layer, etc.) should be properly prepared, brought to specified grade, and compacted. Mattress units should be placed in position at the proper elevation and in the proper alignment and pattern as shown on the engineering drawings. Mattress units up to 35 ft in length can be lifted from both ends using spreader beams as illustrated in Figure 3 or from one end (as shown in Figure 11). The contractor may determine which method is most suitable based on certain site conditions. Units should be lifted from the horizontal position in a manner that minimizes severe bending or distortion of the top and bottom geogrid layers. The goal is to maintain fairly uniform tensioning of the geogrid across the width.

Units can be maneuvered into position using tag lines, but personnel must stay clear of the area beneath units and support rigging at all times during lifting and placement. If divers are needed to guide underwater placement of mattresses, they must exercise extreme caution and adhere to the dive plan. After initial placement, mattresses can be lifted and repositioned as final adjustments are made. Generally, it is not necessary to connect adjacent mattresses once placed. If the mattress has a preattached geotextile filter, care must be taken to assure proper overlap of the fabric as the mattress is placed.

**Anchoring.** Where specified, tieback anchors should be installed with the anchor point located landward of any potential soil failure (e.g., slip surface failure), erosion of backfill, etc. Geotechnical engineers should be involved in this aspect of design.

**Repair.** Damage to mattress geogrid or seams during fabrication, filling, or installation can be repaired provided damage is limited to relatively small areas. Seams can be relaced if the adjacent panels have not separated. If the rock fill has already been compacted, it may not be possible to draw the seam together. In this case, a patch can be applied by stitching on a section of geogrid. Damage to the geogrid of filled mattresses should be repaired by stitching on a patch of new geogrid that covers the damaged area with at least 6 in. overlap in all directions. Damage to the mattress container prior to filling with stone should be repaired by replacing the entire damaged geogrid panel.

Mattresses that have been damaged after being put into service on a project can be either repaired in situ or removed and replaced with new mattresses. In situ repair requires replacing any lost stones and applying a patch as previously described. This should only be done for small breaches of the geogrid or seams, and preferably only on mattresses that are not directly exposed to wave action. In cases where damage covers a wider area, or when two or more mattresses are damaged, it may be possible to remove the damaged mattresses and replace them with new units.

Removal and replacement will be more difficult if the rock fill is not contained during lifting of the mattress. Mattresses placed on sandy bottoms will trap sand in the voids between the rock fill, thus increasing the weight of the mattress to the point that it cannot be lifted out of the water without risking failure of the geogrid or the seams. When this situation arose at the Seabrook mattress installation, it was discovered that the sand-burdened mattresses could be lifted off the bottom and gently agitated to shake out the sand before lifting the mattresses out of the water. However, the initial lifting of the heavier mattresses required equipment with greater lifting (and potentially booming) capacity than deployed during original placement.

In dynamic areas where marine mattresses are placed as a bedding layer or a structure under-layer, consider potential storm impacts that could occur prior to placement of the overlying core material or armor stone. Stockpiling of fabricated mattresses within the water body adjacent to the placement site should be strongly discouraged.

**MARINE MATTRESS COST:** Costs for installed marine mattresses depend on such factors as application, proximity and cost of rock-fill material, site accessibility, placement method (land-based or from barge), availability of equipment, and project size. Table 1 lists typical cost estimates for installed mattresses expressed in U.S. dollars as of 2005. These estimates should be considered only as guidelines for initial cost estimating during evaluation of project alternatives.

**Table 1**
**Installed Mattress Cost per Square Foot**

| Application | Mattress Placement | Mattress Thickness | Cost per square foot |
|---|---|---|---|
| Breakwater construction | In water | 12 in. | $15 |
| Riverbank revetment | On land | 12 in. | $10 |
| Revetment foundation | In water | 6 in. | $13 |

**EXAMPLE MARINE MATTRESS APPLICATIONS:** The following brief case histories summarize several successful applications of marine mattresses in coastal engineering projects.

### Shoreline Protection Revetment, Cape May State Park, Cape May, NJ.

**Problem.** Chronic dune and shoreline erosion that threatened park buildings.

**Project description.** The project, completed in April 1996 by the New Jersey Department of Environmental Protection, involved reconstructing portions of the eroded dune using concrete construction debris covered by a layer of sand. The reconstructed dune was then protected over a length of several 100-ft with 12-in.-thick marine mattresses as shown in Figure 7. The lower portion of the mattresses extended into the intertidal zone, but the mattress toe was not embedded or protected with an apron. Instead, a row of armor stones was placed seaward of the mattress toe for stabilization. Cape May has a mean spring tide range of 5.5 ft, and during each tide cycle the revetment toe and the lower portion of the mattresses are exposed to wave action that eventually covered the toe with sand. The project was extended to protect a reach of adjacent shoreline in May 1998. The main differences from the original construction were that no

Figure 7. Cape May State Park shore protection mattress revetment shortly after placement (photograph from Jeffrey Gebert, Philadelphia District)

concrete debris was used to build the dune, and a crushed stone bedding layer was placed beneath the marine mattresses. In November 2004, the mattress revetment was buried by a Philadelphia District beach-fill project that extended from Lower Cape May Meadows to Cape May Point.

**Project performance.** The marine mattress revetment was exposed for 8 years before being covered by the beach-fill project. During this time, the revetment fulfilled its purpose with no reported damage or loss of functionality. Over time, some of the overlying sand washed into voids between the concrete debris used in dune construction, which resulted in an irregular and steeper mattress foundation. Subsequent shifting of the mattress units due to the loss of support apparently was not significant enough to jeopardize the revetment. A storm in 1997 reportedly exposed the installation to waves reaching 8 ft or more with subsequent overtopping of the revetment. Portions of the revetment were extended landward over the dune crest with additional mattresses to provide anchorage and dune overtopping protection.

### Barnegat Inlet Lighthouse Scour Protection.

**Problem.** A 50-ft-deep scour hole caused by strong flow velocities during ebb tide threatened to erode the inner bank shoreline of Barnegat Inlet and undermine the revetment protecting the foundation of Barnegat Lighthouse. A traditional loose-stone scour blanket overlaying geo-synthetic filter cloth could not be used because of the swift currents that would displace the geotextile before it could be effectively covered with revetment armor stones.

**Project description.** Barnegat Lighthouse stands on the bay side of the south jetty at Barnegat Inlet. The Philadelphia District stabilized the landward slope of the large scour hole, shown on Figure 8, with an underwater revetment in February 2001 for an estimated cost of $1.4 million. The revetment extended from the bottom of the scour hole up the landward side a distance of about 30 ft, and it was constructed of armor stones weighing between 500 to 800 lb placed over a bedding layer of marine mattresses. Individual mattresses measured 5 ft by 20 ft by 4 in. thick with interior baffle compartments spaced at 2-ft intervals to prevent shifting of the rock fill. The bottom of the geogrid was lined on the inside of the mattress containers with a geotextile fabric, and the mattresses were filled while lying horizontal with material having diameters between 1.5 and 3.0 in. After filling, the top section of geogrid was stitched to the bottom, sides, and interior baffles. Rather than placing mattresses individually, up to six mattresses were tied together to form mats measuring 20 ft by 30 ft. Mat placement could only occur during ebb tide when currents are reduced, and the lashing together of mattresses allowed rapid mat placement during the ebb tide construction window. Adjacent mats were overlapped by at least 18 in., so using larger mats reduced the number of required overlaps. Mat placement was guided by GPS and side-scan sonar. Divers and an underwater video camera mounted on the spreader rig verified accurate placement. Any gaps between placed mats were covered with individual 6-ft by 20-ft mattresses. The project required a total of 162 individual mattresses covering an area of approximately 15,000 sq ft. Figure 9 shows placement of the scour mats from a barge located over the scour hole at Barnegat Inlet.

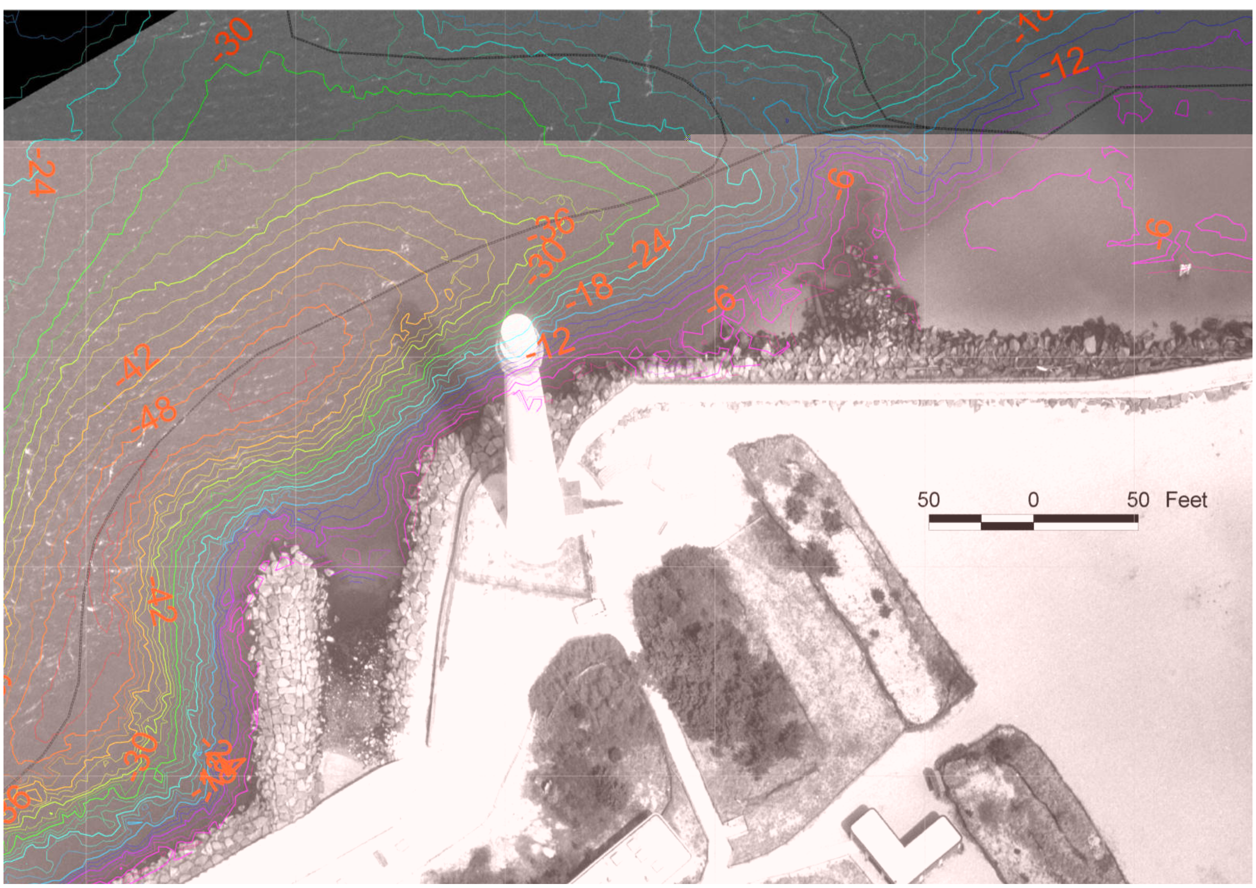


Figure 8. Hydrographic survey showing scour hole near Barnegat Lighthouse (image provided by Jeffrey Gebert, Philadelphia District)

Figure 9. Barnegat Lighthouse with mattress placement underway (photograph provided by Jeffrey Gebert, Philadelphia District)

The marine mattress served three purposes: (a) sink the geotextile filter cloth and hold it in position until the overlying armor could be placed, (b) serve as a bedding/filter layer protecting the filter cloth from damage by the larger revetment armor stones, and (c) reduce any differential settlement of the revetment armor. An additional advantage of the mattress system was relatively easy placement with a high degree of accuracy and assurance of complete coverage.

**Project performance.** The project appears to be functioning as designed, but no monitoring of the revetment installation as been completed as of the date of this technical note.

## Groin Foundation Mat, Tybee Island, GA.

**Problem.** The south beach of Tybee Island, GA, was retreating due to an existing groin updrift of the project site that deprived the beach of littoral sediment and erosion caused by tidal currents associated with the Back River to the east.

**Project description.** The Tybee Island southern shoreline was stabilized in the spring of 1995 by placement of a 285,000-cu yd beach fill north of the existing groin and construction of one L-head groin and two T-head groins south of the existing groin (Figure 10). The beach between


Figure 10. Terminal groin field at Tybee Island, GA (photograph courtesy of Olsen and Associates, Inc.)

the new groins was nourished with 50,000 cu yd of sand. The Georgia Port Authority sponsored the project. Special provisions of the Georgia Department of Natural Resources permit required that the groin structures allow for future adjustment if the need arose. This prompted the project engineer to design groins using a pyramid of three stacked triangular-shaped, 14-ton precast concrete block units encasing a rock core (Olsen 2001). The concrete modules could be removed or repositioned more readily than traditional rubble-mound structures. Groin effectiveness and long-term stability of the precast units required minimizing differential settlement of the groin and preventing local scour by waves and tidal current that could undermine the edges of the groin. These criteria were fulfilled using a foundation constructed of 10-in.-thick marine mattresses with widths of 4.5 ft and lengths ranging between 10 and 28 ft. Mattresses were filled with stones ranging in size between 1.5 and 3.5 in. while supported vertically similar to the photograph shown in Figure 6. Fixed vibration devices spaced at 8-ft intervals along the supporting frame compacted the rock as the mattresses were filled. Completed units could be lifted from only one end without failing the geogrid.

Groin trunks were approximately 280 ft in length with the T-head lengths about 175 ft and the L-head length about 105 ft. Nominal base width of the groin trunks and heads was 22 ft, and the foundation mat extended at least an additional 2 ft on each side as toe protection. Mattresses were placed directly on the sand without a geotextile filter cloth, and their large size kept them stable in the wave and current environment until the groin modules were placed. The final step was construction of rubble-mound round heads at the end of the L-head and T-heads. Groin compartments were partially nourished with sand within 3 months of groin completion.

**Project performance.** The shoreline stabilization project was comprehensively monitored for 3 years after completion, and the project engineer continued personal observations of groin performance biannually. After 5 years, the groin modules continued to be well aligned with no visual signs of differential movement or settlement due to waves or tidal current (Olsen 2001). Olsen attributed the modular groin stability to the marine mattress foundation.

## Toe Protection for Bulkhead at River Street Cut, Seabrook, NH.

**Problem.** Course changes of the Blackwater River resulted in localized bank and bar erosion along River Street and channel/harbor shoaling at the Seabrook Piers and mooring field.

**Project description.** The erosion channel along River Street was filled with dredged material. The placed material was contained on both sides by fiberglass-reinforced polymer (FRP) composite vertical sheetpile walls. Figure 11 shows the location of the bulkheads. The project was a collaborative effort between the U.S. Army Engineer District, New England, and the state of New Hampshire, and was constructed as part of the Corps' Section 227 Demonstration Project. Toe protection against scour by waves and currents was installed in 2004 and 2005 using 12-in.-thick marine mattresses measuring approximately 5 ft wide and 30 ft long. Figure 12 shows one of the mattresses being maneuvered into place while suspended by one end. The dredged material containment sheet-pile walls are also shown in Figure 12 before fill placement. With a mean spring tide range of 9.5 ft, some of the mattresses could be placed above water at low tide. The project was completed in 2005, and monitoring was ongoing as of the date of this technical note.

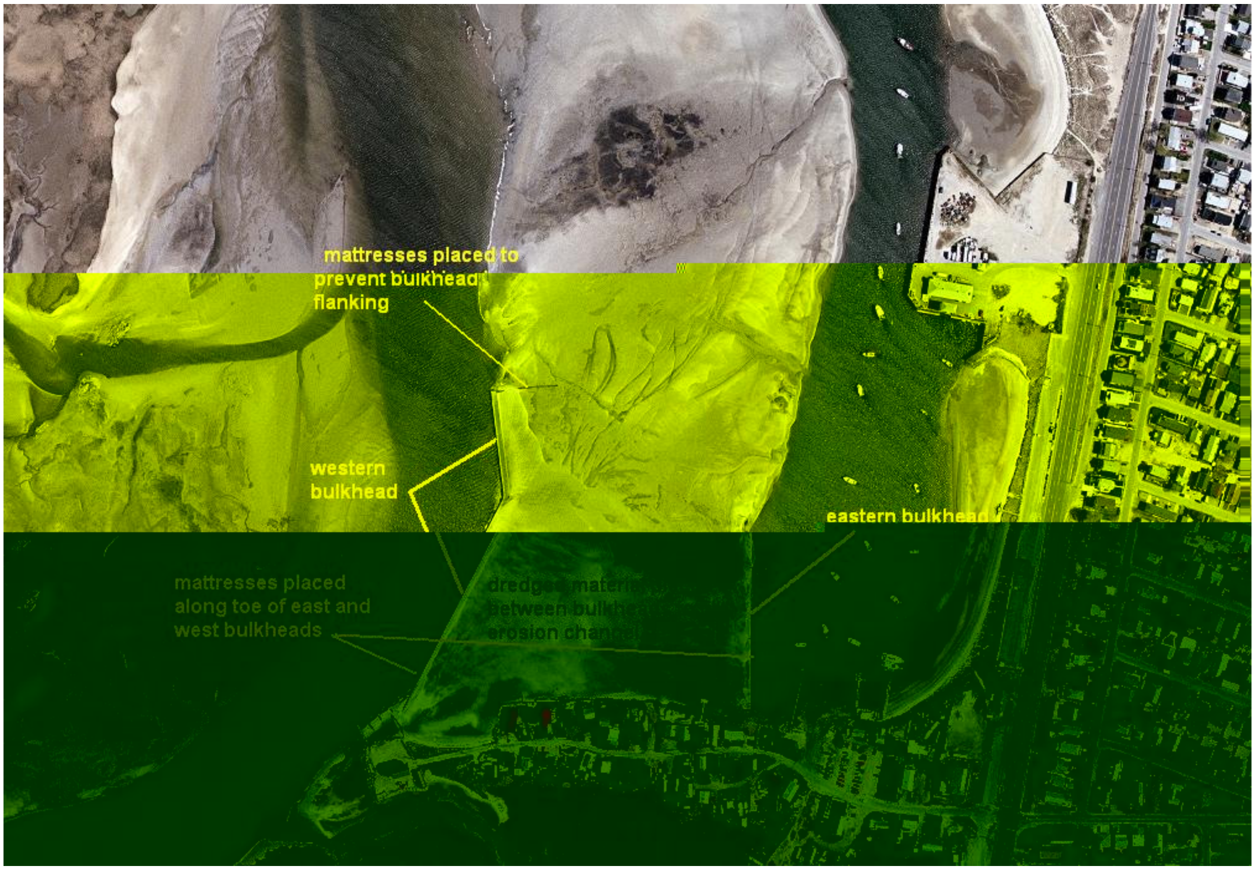


Figure 11. Aerial view of mattress placement at Seabrook, NH, Section 227 project (image provided by Kevin Knuuti, CHL)

Figure 12. Mattress placement at Seabrook, NH, Section 227 project (photograph by Scott Leonard, New England District)

**Project performance.** Informal post-construction observations indicate the marine mattress scour protection is functioning as intended. Figure 13 shows in situ mattresses along a portion of the vertical containment wall at low tide. Scour is evident, and the outer edges of the mattresses have slumped into the scour hole and become partially buried, thus providing protection. Sand deposited atop the mattresses and on the horizontal wale shown on Figure 12 might have been spillover from the original filling of the channel, or it may have been deposited by wave and current action.

**Additional Projects Using Marine Mattresses.** Additional projects that have utilized marine mattresses are briefly described here. (Extracted from Tensar Corp. project summary information).

Project: Sunny Isles Beach renourishment.

Mattress application: Submerged foundation mat.

Installation date: Summer 2001.

Figure 13. Scour apron at Seabrook Section 227 project at low tide (photograph by Scott Leonard, New England District)

Summary: The U.S. Army Engineer District, Jacksonville, constructed two 375-ft-long detached breakwaters in 8- to 10-ft depths to protect a beach nourishment project in Miami, FL. The breakwaters were built as homogeneous structures using 3.5- to 6.5-ton stones placed directly on a foundation mat made of 12-in.-thick marine mattresses.

Project: Holly Beach breakwater.

Mattress application: Submerged foundation mat.

Installation date: Spring 2002.

Summary: The Louisiana Department of Natural Resources placed marine mattresses as foundation mats during a project to increase the effectiveness of 14 existing breakwaters intended to reduce wave energy between Holly Beach and Constance Beach. The Louisiana coast is prone to problems with weak foundation soil that causes structure subsidence and differential settlement. Foundation mats made of 12-in.-thick marine mattresses provided a uniform foundation that distributed the load evenly, minimized the quantity of foundation material, and simplified underwater construction.

Project: Fort Clinch state recreation area shoreline protection extension.

Mattress application: Groin foundation mats.

Installation date: January 2000.

Summary: Fort Clinch is situated at the north end of Amelia Island, FL, next to the Amelia River. Four T-head groins were installed for the Florida Department of Environmental Protection, Florida Park Service, to protect Fort Clinch from chronic erosion due to waves and strong tidal flows. Previous groins experienced scouring and structure undermining. The heads of the rubble-mound groins were constructed on top of 12-in.-thick marine mattresses placed on the relatively steep foreshore slope. In addition to providing foundation support, the mats extended 8 ft beyond the groin leading edge as a scour apron. No trenching or anchoring of the mattresses was required (Olsen 2001).

Project: Point Mugu Naval Air Weapons Station seawall repair.

Mattress application: Shoreline and channel protection.

Installation date: March 1997.

Summary: The Department of the Navy repaired a seawall in Oxnard, CA, damaged by heavy wave action and tidal currents at an inlet. Heavy marine mattresses 2-ft thick were placed to stabilize an area flanking the seawall near the mouth of the inlet.

Project: Hereford Inlet seawall.

Mattress application: Revetment bedding mat.

Installation date: 2005.

Summary: The Philadelphia District constructed a deepwater submerged revetment to protect the toe of an existing deteriorating seawall situated along the bank of Hereford Inlet. (A new 13,000-ft-long seawall was also part of the project). The 6-in.-thick marine mattresses lined with geotexile filter cloth were used as the revetment bedding layer. The mattress served as ballast for the filter fabric, making installation easier and assuring complete coverage. It also protected the filter cloth from punctures during placement of the revetment stone. This application is similar to the Barnegat Inlet scour protection previously described in more detail.

Project: Stratford Army Engine Plant Causeway protection.

Mattress application: Contaminated sediment cap.

Installation date: November 2001.

Summary: The Federal government deployed 12-in.-thick marine mattresses to cap contaminated sediments placed as part of a causeway extending into Long Island Sound near the Housatonic River. The causeway is protected from river/tidal currents and waves by a revetment. Because of the importance of capping the contaminated sediment, greater quality control than usual was exercised for this project. The mattresses appear to function well as a substitute for the 4-in.-thick layer of clean sand normally used to cap contaminated sediments.

**SUMMARY:** This CHETN has described marine mattresses consisting of small stones held by a container fabricated from geogrid. Coastal project applications for marine mattresses include revetments, foundation mats, scour mats, rubble-mound structure underlayers, structure toe protection, pipeline and outfall protection, and scour protection in advance of construction. Advantages of marine mattresses over comparable loose stone include offsite fabrication, fast and accurate placement, uniform coverage (particularly underwater), durability, rock-fill availability, stability, and capability to distribute loads over weak foundation soils.

Examples of successful projects that deployed marine mattresses were briefly discussed. One fairly common theme in the presented examples was the installation of marine mattresses in situations where adverse flows or waves would have made placement of geotextile filters and loose bedding materials problematic. Mattresses have also served effectively as revetment armoring in low to moderate wave climates. However, the curves in this technical note representing allowable wave height for downslope and uplift stability are not based on mattress-specific testing, so the guidance should be considered preliminary until additional research is available.

**POINTS OF CONTACT:** This CHETN is a product of the Coastal Structures Asset Management Work Unit of the Coastal Inlets Research Program (CIRP) being conducted at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. Questions about this technical note can be addressed to Dr. Steven A. Hughes (Voice: 601-634-2026, Fax: 601-634-3433, email: Steven.A.Hughes@erdc.usace.army.mil). For information about the Coastal Inlets Research Program (CIRP), please contact the CIRP Program Manager, Dr. Nicholas C. Kraus at 601-634-2016 or at Nicholas.C.Kraus@erdc.usace.army.mil. Beneficial reviews were provided by Messrs. Jeffrey A. Gebert and Douglas C. Leatherman, Philadelphia District, Kevin Knuuti, CHL; Erik J. Olsen, PE, Olsen Associates, Inc.; and Jeff Fiske, Tensar Corp. This technical note should be cited as follows:

> Hughes, S. A. (2006). "Uses for marine mattresses in coastal engineering," ERDC/CHL CHETN-III-72, U.S. Army Engineer Research and Development Center, Vicksburg. MS

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***NOTE:***